An Abaqus-embedded Optimizer for Composite Components

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The use of fiber reinforced composite materials is continuously increasing for all kinds of lightweight structures, in particular in space, aviation and automotive industry. The full utilization of their beneficial mechanical properties requires a proper alignment of the reinforcement. For that purpose a considerable number of optimization techniques have been developed [1-3]. The treatment of complex structures of industrial concern, which might involve metallic components, bolts, and a high variability in the requirements for composite components, however, still requires a large amount of heuristic practise.

Inspired by the ideas of "fibre steering" (aligning the fibres along the most effective direction), "computer aided internal optimization" [4], and "multi-domain topology optimization" [5] a finite element based layup optimization procedure is proposed. The global objective function is the total mass of the structure under consideration. The procedure is applicable for large finite element models (several million degrees of freedom) of complex shell structures involving metallic and composite (monolithic laminate and sandwich) components assembled by bolted joints. The approach rests on an iterative procedure determining the material thickness, the stacking sequence of laminate components, and the dimensioning of bolted joints from the local stress/strain state at the level of the finite element routine.

The functionality of the core routine of the optimization procedure called by the element routine is subsequently sketched exemplarily for monolithic laminate components: Section force and moment vectors as well as their principal directions are calculated at the element centre. For each of the four directions, the minimum number of plies is determined to meet a unidirectional strength criterion. From these numbers, the dominating direction (0°) and the required moment of inertia of the cross-section are identified. Further, a grouping parameter n is calculated from the degree of anisotropy of the stress state. The proposed stacking then follows a strict sequence, $45/90/\text{-}45/0_n$, e.g., which is repeated until the required membrane and bending stiffness is obtained. Even simpler algorithms apply for sandwich and, in particular, for metallic components. The element-wise determination of the stacking sequence is embedded in an incremental procedure, which can also be adapted for a, maybe large, number N of load cases, say 50 -100. The data handling is organized by means of a SQLite database. The element routine and the optimization routine directly communicate with the database. The proposed algorithm involves a certain freedom in modifying its constituents (strength criteria, stacking rules, etc.). It can be linked with a large class of finite element routines, geometrically linear as well as non-linear ones. For the Abaqus implementation an adapted and refined version of the shell finite element formulation proposed in [6-7] has been implemented as a user subroutine (UEL).

The procedure has been tested and applied in the course of the design phase of Boeing 777 and Airbus 350 winglets. The optimized design is compared with real-life ones concerning mass, strength, stability, and serviceability. The quality of the ‘optimum’ is demonstrated by means of a stochastic sensitivity analysis analyzing the influence of changes of design parameters, and in particular of deviations arising from the fabrication procedure.

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